Water-Fat Separation at 3T with IDEAL and 3DPR

E. K. Brodsky[1], S. B. Reeder[2,3], H. Yu[4], W. F. Block[3,5]

[1]Electrical Engineering, University of Wisconsin, Madison, WI, United States, [2]Radiology, University of Wisconsin, Madison, WI, United States, [3]Medical Physics, University of Wisconsin, Madison, WI, United States, [4]Global Applied Science Lab, GE Healthcare, Menlo Park, CA, United States, [5]Biomedical Engineering, University of Wisconsin, Madison, WI, United States

INTRODUCTION

IDEAL [1,2] is a multipoint chemical shift based water-fat decomposition technique that provides uniform separation of water and fat in the presence of B_0 and B_1 inhomogeneities using three or more complex images acquired at arbitrary echo spacings. VIPRME [3] is a highly efficient 3D projection reconstruction (PR) sequence that acquires multiple half-echos at separate projection angles after each excitation. Previous work has demonstrated VIPRME implementations acquiring four or six half-echos during each TR, but VIPR is easily extended to acquire eight or more half echos. Typically, all the half-echos have been combined using complex addition to yield an image with high SNR and inherent partial fat suppression. However, the fat suppression, like other frequency-selective techniques, fails in regions of high magnetic field inhomogeneity. The multiple echos, even though they each sample separate sets of projection angles, adequately sample low spatial frequencies, allowing the generation of a low resolution field map. As B0 inhomogeneities tends to vary slowly, this is sufficient to aid in water-fat decomposition.

Echo time optimization for three point acquisitions [4] has shown that the optimal phase shifts between water and fat occur when the middle echo is acquired with their phases in quadrature and the other two echoes are acquired $2\pi/3$ before and after the middle echo (i.e. $-\pi/6+\pi k$, $\pi/2+\pi k$, $7\pi/6+\pi k$; k=any integer). With these combinations of echoes, the maximum SNR performance of the estimation can be achieved, with an effective signal averaging of three.

MATERIALS AND METHODS

IDEAL VIPR was tested on a General Electric HD Excite 3.0T scanner with TwinSpeed gradients and a single channel transmit/receive extremity coil. Scans were performed on a spherical fat/water phantom consisting of peanut oil floating on 0.9% normal saline doped with 5mM $NiCl_2$ using a VIPR SPGR acquisition with 2 mm isotropic resolution over a 32 cm spherical FOV, a TR of 5.7 ms and TEs of 2.2, 3.0, and 3.8 ms, a combination that achieves optimal fat/water decomposition performance at 3T. Additional half-echos were acquired at 1.3 and 4.7 ms, but were not used in the IDEAL reconstruction. A human knee study imaged a 20 cm FOV with 0.78 mm isotropic resolution, collecting 140,160 unique angles in 17,520 readouts over a two minute scan, with a TR of 6.9 ms, a bandwidth of ±167 kHz, and a flip angle of 7°. The TEs were 1.9, 3.0, and 4.1 ms, the best echo spacing that could be achieved at this resolution without exceeding dB/dt limits.

Each dataset was reconstructed to generate three complex images, one for each echo time. These images were processed with an implementation of the IDEAL algorithm that generated a low-resolution B0 field map, which was used to calculate water and fat images.

RESULTS AND DISCUSSION

Figure 1 shows water and fat images of axial slices from the phantom scan. The water image demonstrate a water:fat signal ratio of 8; the fat image a fat:water ratio of 13. The residual fat signal in the water image is expected and caused by a small fat resonance occurring close to the water resonance.

Figure 2 shows water and fat images of the knee study. Sagittal images showed uniform separation of water from fat across all images with excellent depiction of the articular cartilage

Additional work remains in analyzing and optimizing this combination of methods. As radial acquisitions collect data at varying projection angles, it is important to examine how the resulting phase errors affect the fat/water decomposition. Unlike Cartesian acquisitions, the "echo time" interval for radial imaging varies with spatial frequency and can only be uniformly correct at the center of k-space. Correcting the resulting phase errors may improve image quality. Additionally, a slightly different set of projections is used for each echo – while this is known to reduce streak artifacts when the echos are combined into a single image, the full effect on fat/water decomposition remains to be understood. Various methods for choosing and interleaving projection angles must be investigated.

The current implementation does not use the half-echos from the dephaser and rephaser, avoiding the complexity of processing a dataset with images based on both half-echos and full echos. It is likely these half-echos can be used, though this may change the optimal echo spacing.

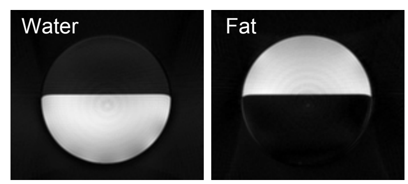

Figure 1: Images of a fat/water phantom shows decomposition of water (left) and fat (right) from a single scan.

Figure 2: Sagittal (top) and coronal (bottom) images of the knee demonstrated uniform separation of water and in all images covering the knee. Excellent depiction of the articular cartilage is noted.

CONCLUSIONS

This work demonstrates the feasibility of combining IDEAL water-fat separation methods with rapid multi-echo 3DPR imaging at 3.0T. This method shows promise as a useful clinical technique for imaging challenging regions of the body such as the torso and extremities where B_0 inhomogeneities may lead to inadequate fat saturation. The technique does not require an increase in scan time and actually increases data acquisition efficiency. The IDEAL reconstruction also limits streak artifacts from fat at the edges of the FOV and can be applied to time-resolved VIPR imaging.

REFERENCES AND ACKNOWLEDGEMENTS

1. SB Reeder, *et al.*, MRM 51(1):35-45 ('04)
2. SB Reeder, *et al.*, Proc. 13th ISMRM, 105 ('05)
3. AV Barger, *et al.*, MRM 48:2, 297-305 ('02)
4. AR Pineda, *et al.*, MRM 54(3):625-635 ('05)

Research was supported by NIH 8 RO1-EB002075-07. The authors appreciate the assistance of GE Healthcare.